PROBABILISTIC GRID PLANNING WITH CONSIDERATION OF DISPERSED GENERATION AND ELECTRIC VEHICLES

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ABSTRACT

One objective of grid planning for low voltage grids is to determine cable diameters of feeders. This usually involves simulating worst case scenarios to estimate peak loads, although the probability of such scenarios to actually occur is not known. Furthermore, today's grid planning needs to account for new technologies like dispersed generation and electric vehicles. A worst case approach, for example, would consider generation without any simultaneous load. However, in practical experience there is always a minimum load, which mitigates the effect of voltage rise due to generation. This publication presents a new approach to probabilistic grid planning under the consideration of risks of certain scenarios to occur. This methodology can help to plan grids more efficiently.

INTRODUCTION

For the planning of cable diameters grid utilities use practical estimations of the load on a low voltage feeder with a certain number of households connected. By estimating the load occurring on a low voltage feeder it is possible to design the resistance of the feeder in a way that the limiting thermal current is not exceeded and voltage drops stay within given limits and comply with the EN 50 160.

Nowadays, however, new kind of loads like electric vehicles (EV) and even dispersed generation in low voltage grids determine the load on feeders and therefore cannot be neglected in grid planning. In addition, these new loads and generation may occur randomly in low voltage grids making a probabilistic view necessary.

This contribution shows a novel approach how to take these new technologies into account. When planning a feeder e.g. for 10 households, there is a certain probability for EV or photovoltaic (PV) systems to be present, which will change the expected peak load. Therefore, a probabilistic load model for EV is developed and combined with measurement data of households and PV systems to calculate an expected peak load on a feeder. This probabilistic model takes the time of arrival of vehicles, daily travelled distances and distribution of EV into account. Therefore, this load model is able to yield the probability of certain charging loads to occur.

Furthermore, not only the peak load, but also the minimum load or negative peak load is important when considering PV systems. What minimum consumption can be expected when PV systems supply their peak load during noon to mitigate voltage rise, is an interesting question.

This contribution proposes a methodology, with which it is possible to condense the complicated derivation of probabilistic load profiles to simple guidelines for grid planning under certain assumptions for load and generation.

MODELLING OF HOUSEHOLDS, ELECTRIC VEHICLES AND PHOTOVOLTAICS

To assess the impact of PV or EV on the grid, it is very important to have a good understanding for the behaviour of loads and generation. Therefore, load models are required. For households and PV, these can be developed easily using measurement data [1,2]. For EV, however, no measurement data exists yet. Assuming that the mobility behaviour of today's car owners does not change significantly when driving an EV, one can assess charging profiles by using survey data [3] regarding daily travelled distances and times of arrival after last trip of the day of all current car owners. Furthermore, by assuming that in the beginning EVs mainly are charged when arriving at home, the start and length of charge can be determined. A more detailed description of the assessment of these profiles can be found in [2].

Additionally, these load models yield the availability of vehicles and therefore an estimate of possible reactive power supply, which can support voltage stabilization in low voltage grids. Besides the availability and demand of energy, the charging power with which the vehicles are connected is needed. An estimation of the distribution of charging powers for 2030 is depicted in Table I.

Table I Distribution of charging power of EV [4].

	3.7 kW	11 kW	22.1 kW	43.5 kW
2030	71.3%	19%	6%	3.7%

By generating many probabilistic EV load profiles, it is possible to assemble an averaged load profile per vehicle, how it is commonly used for households and commercials in grid simulation. For reactive power, it is assumed that every EV, which currently is connected to the grid, is able to supply reactive power in a way that its maximum charging apparent power according to table 1 is not exceeded. These averaged load profiles for active and reactive power, which resemble each single EV, are depicted in fig. 1.

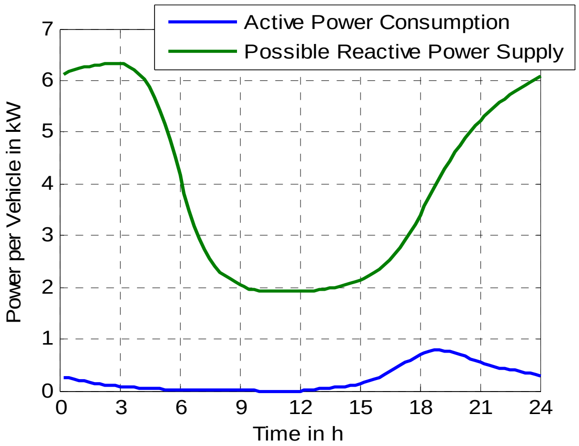

Fig. 1 Average active power consumption and availability of reactive power supply per electric vehicle.

The peak active power consumption arises at around 7:00 pm when most people arrive at home and charge their vehicle. It is almost simultaneous with the peak load of households. Despite the high charging powers, the peak active power consumption only rises to about 1 kW. This is because some vehicles are not moving every day and are not charging simultaneously. This profile is the average of all EVs. On a single low voltage feeder, significantly higher loads may occur. There is a considerable amount of reactive power available through the day. Even during noon there are around 29% [3] of vehicles at home and might be connected to the grid, fully charged and available to supply reactive power.

But besides knowing the mean of power consumption or availability, it is very important to know about the variance, too, since conditions change every day and especially with every low voltage feeder. The developed load model gives the variance for low number of electric vehicles by only generating single vehicle profiles. These can be used to assess possible peak loads in the grid, which is investigated in the next section.

INFLUENCE OF ELECTRIC VEHICLES AND PHOTOVOLTAICS ON EXPECTED PEAK LOAD

As described in the introduction, grid planning sizes cable diameters by estimating peak loads. The maximum peak load a line can carry is determined by two main restrictions, which are the maximum thermal current and maximum voltage drop or rise. The voltage deviation can be estimated when knowing the current on a feeder. Therefore it is sufficient to assess the load on a feeder to be able to design cable diameters. This is possible by looking into measurement data. The throughout the paper used data of loads and generation were collected in the scope of the publicly funded project MeRegio within the German E-Energy Research Program [5], which is supported by the Federal Ministry of Economics and Technology as well as the Federal Environment Ministry. The data consists of 912 smart meters measuring the sum of the active power of the three phases on a 15 min basis in 2010.

For a feeder with e.g. 30 households, one can repeatedly draw 30 household profiles for a day out of the measurement data and resolve the peak load. This sometimes yields higher and lower values with a certain mean and variance and can be combined with PV and EV profiles. This is repeated for 100 000 times and yields as many peak and minimum loads on the feeder. This resembles the distribution of possible loads on the feeder sufficiently. However, for grid planning, a possible maximum peak load is the main design criterion. Under the assumption of a certain risk (for example 1%) that the peak load is higher, a value of the 99th percentile can be assessed as depicted in fig. 2 and can be used for planning purposes. This is repeated for the minimum load as to account for voltage rise due to PV. The peak load only due to household loads is depicted as the two black curves.

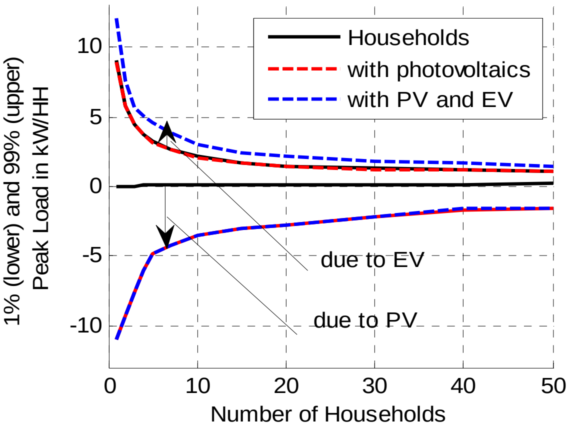

Fig. 2 Peak and minimum load on feeder with influence of photovoltaics (5% of households have a PV system) and electric vehicles (12.5% penetration).

For the peak load, the black curve is directly beneath the red curve. For 10 households a peak load of 2 kW/household is to be expected and the feeder would have to be planned to carry a load of 20 kW. The minimum load is only slightly above zero. However, this changes when PV is added. Referring to data concerning the installed capacity of renewable energies, 5% of households have a PV system commonly found in rural areas of Germany. The minimum load drops drastically exceeding even the positive peak load, which is not affected by PV. By adding EV profiles with a penetration of 12.5% per household, which is the objective of the federal government of Germany for 2030 [6], the positive peak load is raised like depicted with the dashed blue curve.

Certain options to lower the expected peak load can be analysed. One of these, for example, is to limit the power infeed of PV to a certain percentage of the installed capacity. The idea is that this limit is rarely exceeded and therefore the energy loss is small. However, the resulting peak infeed and therefore voltage rise is lowered significantly. Fig. 3 shows the energy loss over power limit for winter, summer and in total for the given PV measurement data.

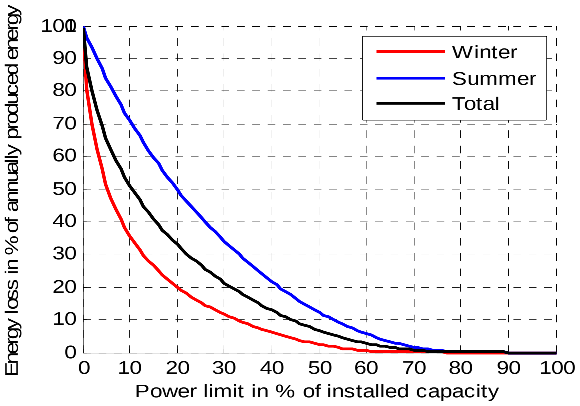

Fig. 3 Exemplary energy loss due to limiting the power infeed of PV.

For a power limit of 70% of the installed capacity, like demanded by the Renewable Energie Sources Act 2012, only 0.7424% of the annually produced energy is lost. Considering only summer, 1.66% of energy is lost due to the power limit. A more detailed analysis of the effect of a power limit on the energy loss is found here [7].

Another option is to consume inductive reactive power with PV to mitigate voltage rise. It is assumed that in urban low voltage grids usually an R to X ratio of ~2 is found. Considering that the voltage deviation is the limiting criterion, 2 kvar reactive power supply can then mitigate the voltage rise of approx. 1 kW active power. Low voltage regulations [8] specify that PV should be able to supply reactive power up to cos φ = 0.9 and cos φ = 0.95 for smaller sized plant capacities.

Fig. 4 shows the exemplary effect of the power limit and reactive power supply on the minimum load under the assumption that active power can be reduced for half the amount of every kVA reactive power supplied. Therefore, not the actual occurring active power on a feeder is depicted, but the remaining active power causing voltage rise.

It becomes clear that both options significantly reduce the appearing load flow, which needs to be planned for. The reactive power supply depicted with the dashed blue curve seems to be even a little bit better than the power limit depicted in red. Both options combined (dashed red) are up to 2 kW lower than in the basic scenario with no actions taken (blue).

Fig. 2 already illustrated the influence of electric vehicles on peak and minimum loads. The minimum load is almost not affected at all. However, EV can supply reactive power as well, as shown in fig. 1, and thereby mitigate the voltage rise due to power infeed of PV.

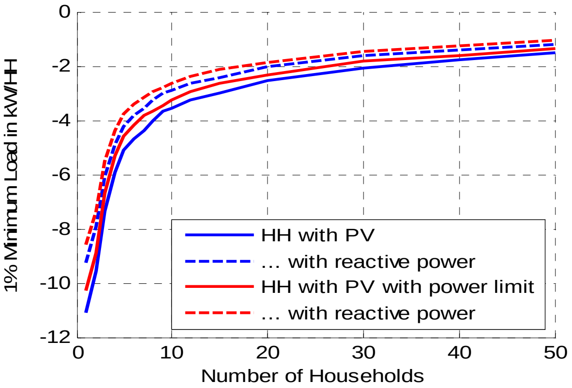

Fig. 4 Minimum active power causing voltage rise on feeder with influence of PV (5%) with and without a power limit of 70% and reactive power supply with cos φ = 0.95.

The effect of EV reactive power supply and a comparison with the two previous options is depicted in fig. 5.

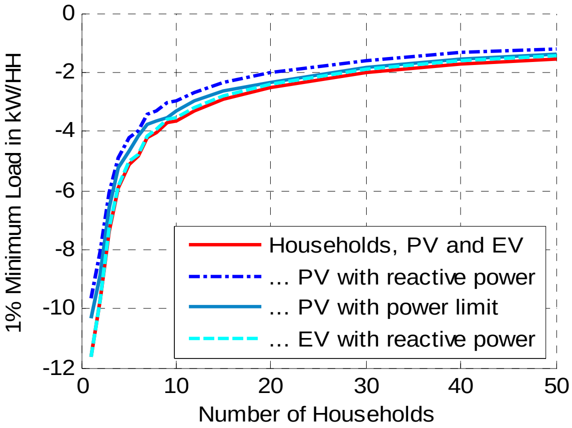

Fig. 5 Minimum active power causing voltage rise on feeder with influence of photovoltaics and electric vehicles.

The light blue curve showing EV with reactive power supply cannot compete with reactive power supply or power limit by PV. Although the amount of available reactive power during noon is smaller as shown in fig. 1, the main reason for the small effect is the small degree of penetration of EV with only 12.5%. For the 1st percentile it is most probable that no or very few vehicles are available at all. Therefore, a grid cannot be planned assuming that vehicles are available supplying reactive power with a penetration as low as 12.5%. However, they can be planned assuming PV systems supply reactive power, because if a critical situation arises due to PV it can compensate for itself.

PROBABILISTIC GRID PLANNING AND REINFORCEMENT

The previous section has shown what loads are to be expected on a low voltage feeder for a given scenario. This scenario consists of a degree of electrification of EV, PV penetration and strategies like power limit or reactive power control for voltage stabilization. Furthermore, the load and generation models can be used to calculate the probability of overloads or even voltage drops with a given grid topology. However, when planning a grid, different conditions might apply for each grid individually. There might be some low voltage grids with an exceptionally high degree of EV, while in others there are none at all. This can already be observed today for PV. Therefore it is necessary to distinguish between the likelihood of an overload for a certain scenario and the likelihood of that scenario to actually occur. A decision must be made whether it is more reasonable to plan the majority of grids, for example, under the assumption of EV or whether it is better to plan more conservatively at reduced costs but revisit those grids, where problems actually occur at a later stage. This mainly depends on costs associated with grid reinforcements, which is why a detailed analysis of finding the optimal planning guideline is beyond the scope of this publication.

A fictional example to illustrate the idea, however, is the following. Given a certain objective for wanted reliability of grids of, for example, 99% that voltage and current limits are not exceeded, one can assess with the methods of the previous section whether a certain scenario is critical and therefore would need additional grid reinforcements or not. A scenario would consist of a grid topology, number of households, number of EVs for this grid, number and size of PV and many more. These are drawn randomly according to a distribution function or an averaged degree of electrification like 12.5% for EV for Germany. However, this means that for a single scenario a much higher degree of electrification of vehicles can occur and therefore cause a critical scenario. A scenario is considered to be critical, if the probability of overload or exceeding voltage limits is higher than reliability allows. This approach yields the probability for the occurrence of a critical scenario for a given grid with given planning guidelines for cable diameters. In a first step, this risk of a critical scenario might be 2%, which means that when every grid is planned with these planning guidelines on average 2% of the grids need to be revisited and reinforced at a later stage. The costs associated with revisiting 2% of grids can be compared with the additional costs resulting from planning guidelines with larger cable diameters for every grid. This would result in a lower risk of critical scenarios and therefore fewer grids requiring revision. The optimal planning guideline is found where these two costs are balanced.

CONCLUSIONS

Grid planning is a task carried out under many assumptions. Current practice is to calculate worst case scenarios without knowing the actual probability of those scenarios to occur. This contribution proposes to use a probabilistic approach, which willingly takes the risk into account to revisit a grid to reinforce it afterwards in case that problems are encountered. Furthermore, this suggests that grid codes like EN 50 160 should not state fixed limits for voltages, but instead demand a certain reliability to stay within these limits. Even with today's planned grids there is a risk of exceeding the limits. Therefore, grid planning needs to be aware of how large the risk actually is to make a feasible decision whether to plan more conservatively or rather accept a higher rate of grids that need to be revisited and reinforced afterwards.

To enable this approach, a methodology was presented how these risks can be assessed. Furthermore, the effect of new technologies like electric vehicles and dispersed generation where taken into account for grid planning. To this extent, load models for PV, households and especially EV where outlined, permitting the estimation of peak and minimum loads at low voltage feeders for different scenarios. Two options to reduce the load on the feeder were presented. One is the limit of feed in power of PV and the other is reactive power control of PV and EV. Both had mitigating effects on the peak load, although reactive power turned out to be more effective. However, reactive power not only helps with voltage control but may increase grid losses.

Finally, an idea was outlined how this probabilistic analysis can be applied to practical grid planning.

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